PROJECT ID # EEMS013

CORE MODELING AND SIMULATION

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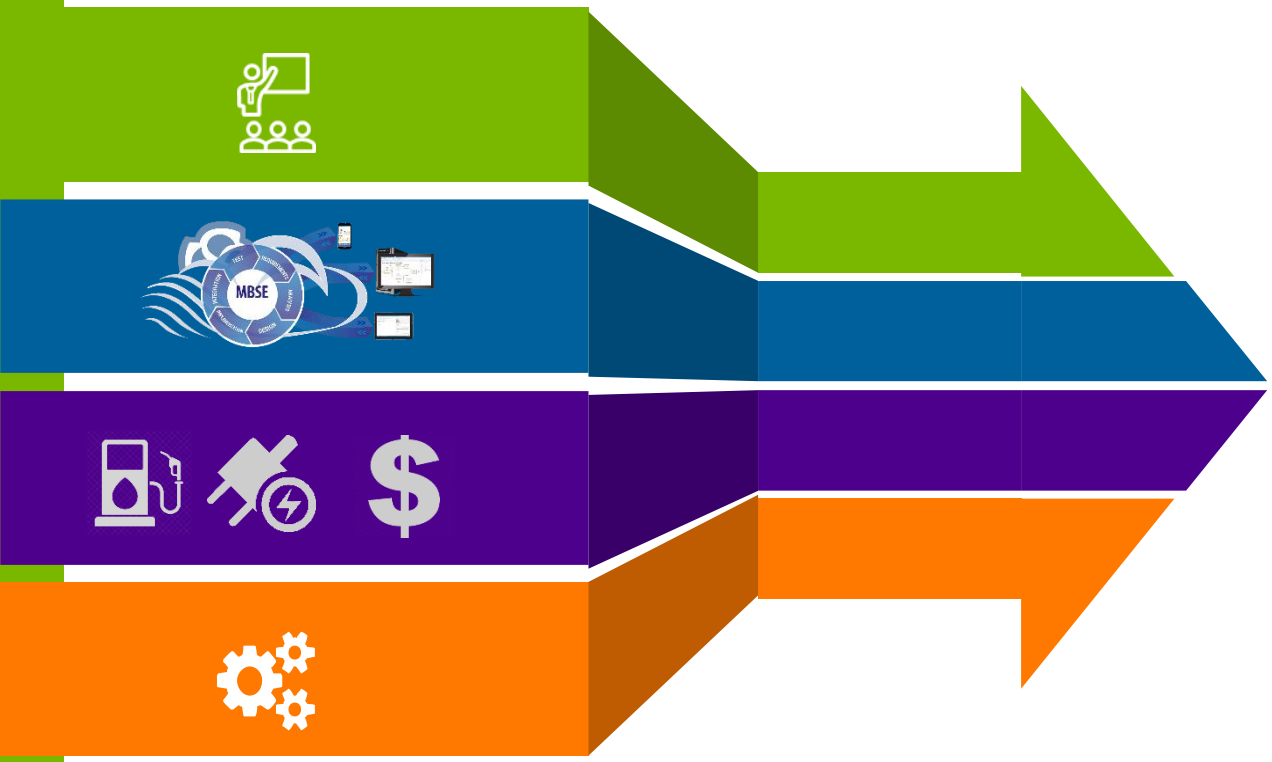
Annual Merit Review 2022, Washington DC

PROJECT OVERVIEW

Timeline	Barriers
• Project start date : Oct. 2021 • Project end date : Sep. 2024 • Percent complete : 20%	• High uncertainty in technology deployment, functionality, usage, impact at system level • Computational models, design and simulation methodologies • Lack of data on individual behaviors relating to e-commerce and freight • Integration of disparate modeling frameworks
Budget	**Partners**
• Total funding: $5,400,000 • FY22 funding received : $1,800,000	• All tool users, both within and outside Argonne (e.g., Ford, Hyundai, Toyota…) • US Government-Industry Partnerships (US Drive, 21CTP)

PROJECT RELEVANCE

Support the DOE Vehicle Technologies Office (VTO) system simulations, with focus on the Energy Efficiency Mobility Systems (EEMS) program



STAKEHOLDERS ENGAGEMENT & DEPLOYMENT

Collect users feedback including issues and new requirements, deploy tools to stakeholders based on their needs

MODEL-BASED SYSTEM ENGINEERING

AMBER: Develop and maintain MBSE platform to estimate the impact of new technologies on mobility, energy, emission, cost, equity… from pure simulation to Vehicle-in-the-Loop.

VEHICLE SYSTEM SIMULATION

Autonomie: Maintain state-of-the-art vehicle energy consumption, performance and system cost estimation across vehicle classes, powertrains and component technologies.
Aeronomie: Aviation electrification with focus on energy consumption

SYSTEM SIMULATION WORKFLOWS

Develop and maintain system simulation workflows designed to answer specific questions from individual component technology (e.g., new engine with single tool) to individual vehicles and large fleets.

>28 Projects were related to EEMS013 during AMR 2021

PROJECT RELEVANCE

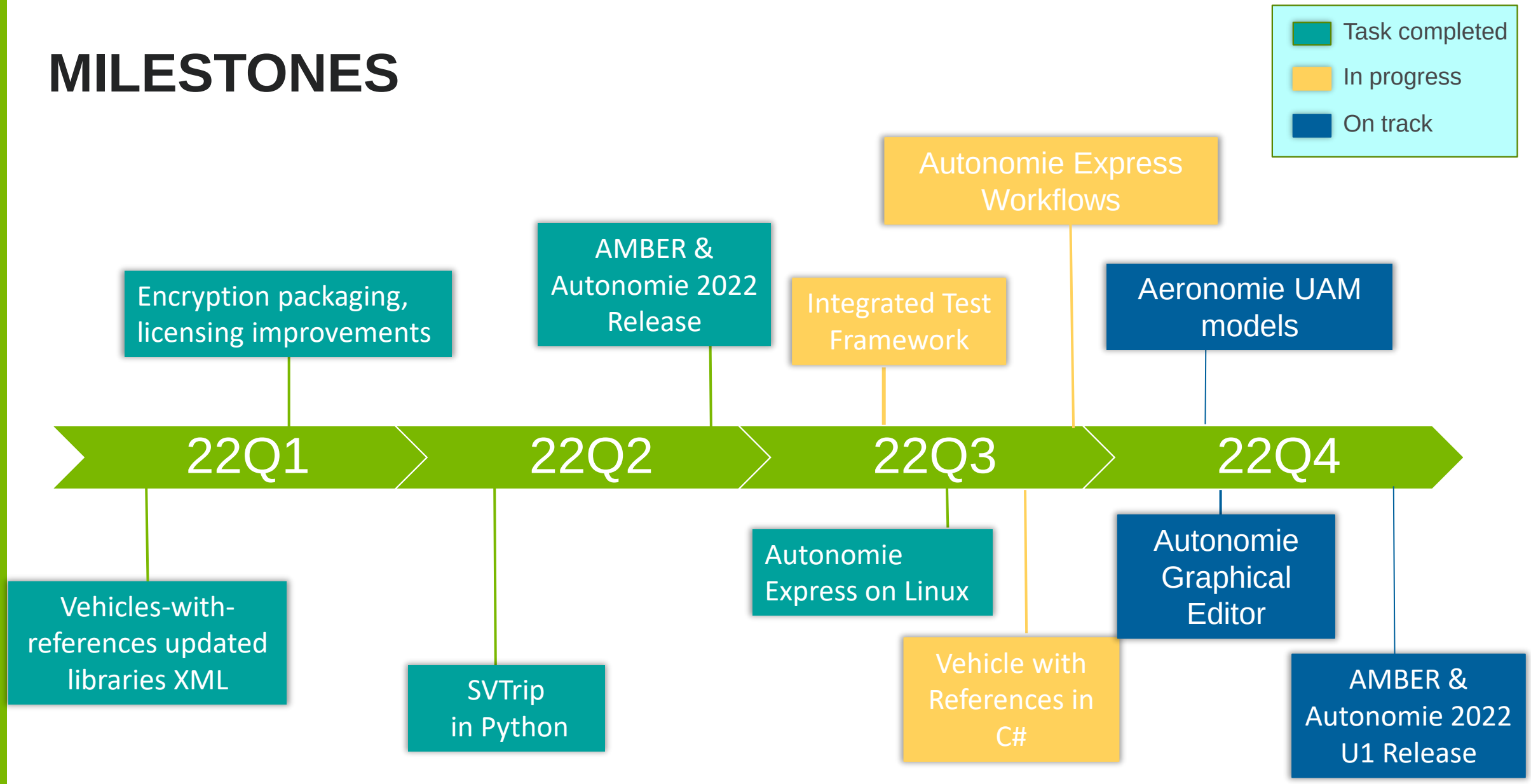
Examples of Applications Supported by EEMS Core

EEMS CORE	Goals / Initiatives
• Technical support, tools maintenance, license management	• Stakeholder engagement
• AMBER development	• Autonomie, SVTrip, RoadRunner, POLARIS, Aeronomie deployments • Stakeholder engagement
• AMBER workflows • Large scale vehicle studies • Compiled vehicles…	• 1M+ simulations (HPC) • Micro & Meso simulations
• Autonomie development	• Component technical targets for light duty (USDrive) and MD/HD (21CTP) vehicles • VTO/HFTO technology benefits • Component performance data, cost • New powertrain sizing
• Aeronomie development	• Urban Air Mobility (UAM) energy consumption

In support of

SMART Mobility
EEMS FOAs
TI FOAs
VTO Tech managers
USDrive
21CTP
Stakeholders

MILESTONES


Task completed
In progress
On track
Autonomie Express Workflows
AMBER & Autonomie 2022 Release
Integrated Test Framework
Aeronomie UAM models
Encryption packaging, licensing improvements
22Q1
22Q2
22Q3
22Q4
Vehicles-with-references updated libraries XML
SVTrip in Python
Autonomie Express on Linux
Vehicle with References in C#
Autonomie Graphical Editor
AMBER & Autonomie 2022 U1 Release

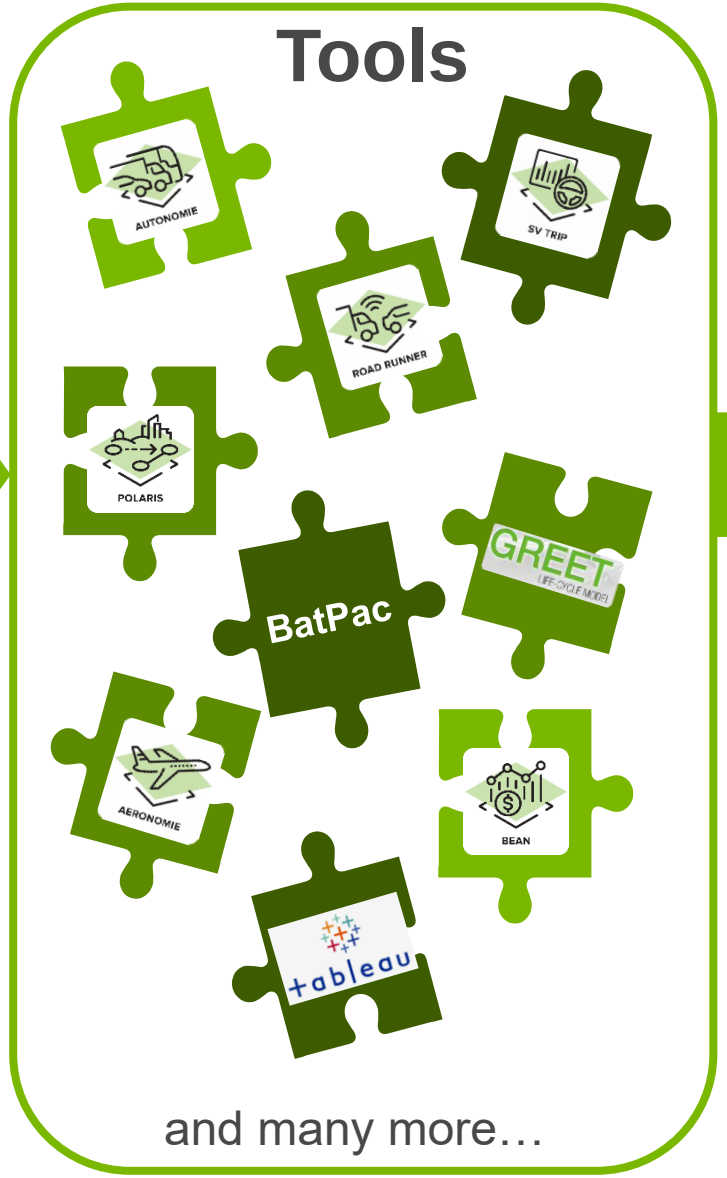
APPROACH

AMBER Framework Designed to Support MBSE System Simulation Workflows

AMBER

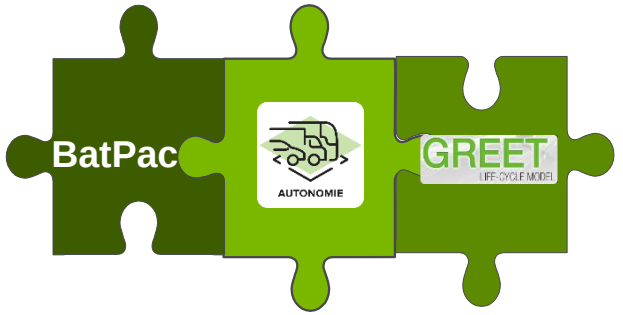
Stakeholder Inputs

Tools

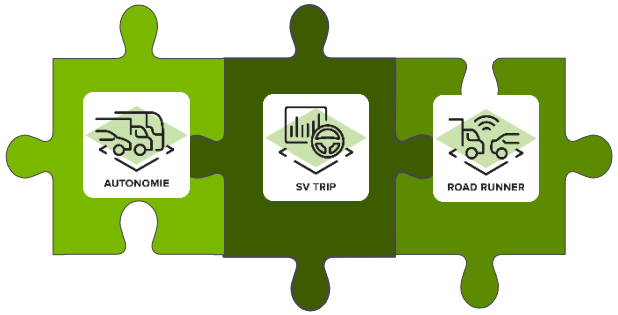


and many more…

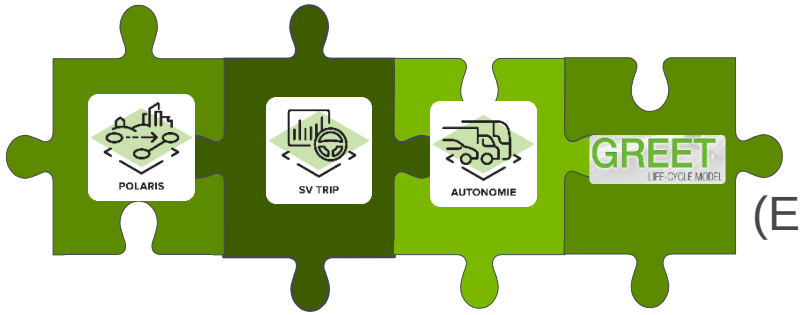
Workflow Examples



Individual vehicle energy, cost and GHG (VAN023)



Energy-efficient control enabled by connectivity and automation (EEMS089)



SMART Mobility Workflow (EEMS093, VAN035)

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APPROACH

Autonomie Continuously Collect Data and Inputs from Public & Private Sources

Vehicle Technical Specifications

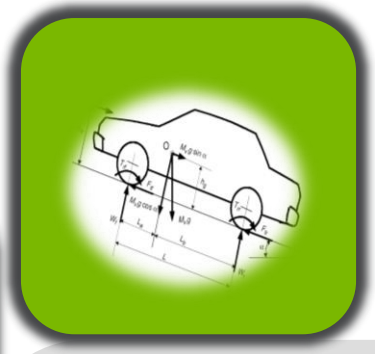
Argonne Vehicle Technology Database (integrate 20 + data sources 1990-2020), A2MAC1…

Vehicle Data

Argonne Advanced Mobility Technology Laboratory (AMTL),D^3, including DOT/NHTSA projects

Component Data

OEMs, suppliers, literature, DOE R&D, DOT/NHTSA…



Driving Cycles / Test Procedure

SAE, OEMs, Suppliers, NREL TSDC/FleetDNA…

AUTONOMIE

Stakeholder Engagement

Issues, new GUI features, new workflows, new vehicles…

Objective: Model any powertrain, component technology, control, test procedure… in the market (now and in the future) from light-duty vehicles to heavy-duty trucks

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

THREE NEW AUTONOMIE PACKAGES INTRODUCED!

Individual Versions Meet Individual Stakeholder Needs

	Stakeholders	Code Access	Applications	Licensing
AUTONOMIE	Vehicle system engineers (developers)	Complete access (Matlab / Simulink / Stateflow required)	Develop new vehicle / powertrain / component / controls	Free for US Gov projects and teaching, Paid license for others,
AUTONOMIE LITE	Vehicle & component engineers (users)	Access to all parameters (Only Matlab Required)	Estimate impact of new component technology, powertrain sizing, parameters…	Free (first release upcoming soon)
AUTONOMIE EXPRESS	Non-vehicle experts	Limited parameter access (e.g., weight), focus on vehicle speed/grade as input (Only Matlab Required)	Simulate large number of real world driving cycles either from simulation (e.g. SUMO, AimSun, VISSIM) or test data	Free (5,000+ vehicles provided)
AUTONOMIE AI	Non-vehicle experts	No parameter access, no 3rd party tools required	Real-time deployment (e.g., Apps), large scale optimization (e.g., traffic light), co-simulation	Free (first release upcoming TBD)

AUTONOMIE UPDATED FOR VTO STUDIES TO EVALUATE NEW & EMERGING TECHNOLOGIES

Supports DOE: EEMS083, EEMS093, EEMS109, VAN023, VAN035 ,VAN038; NHTSA

Component Data

15 New Engines

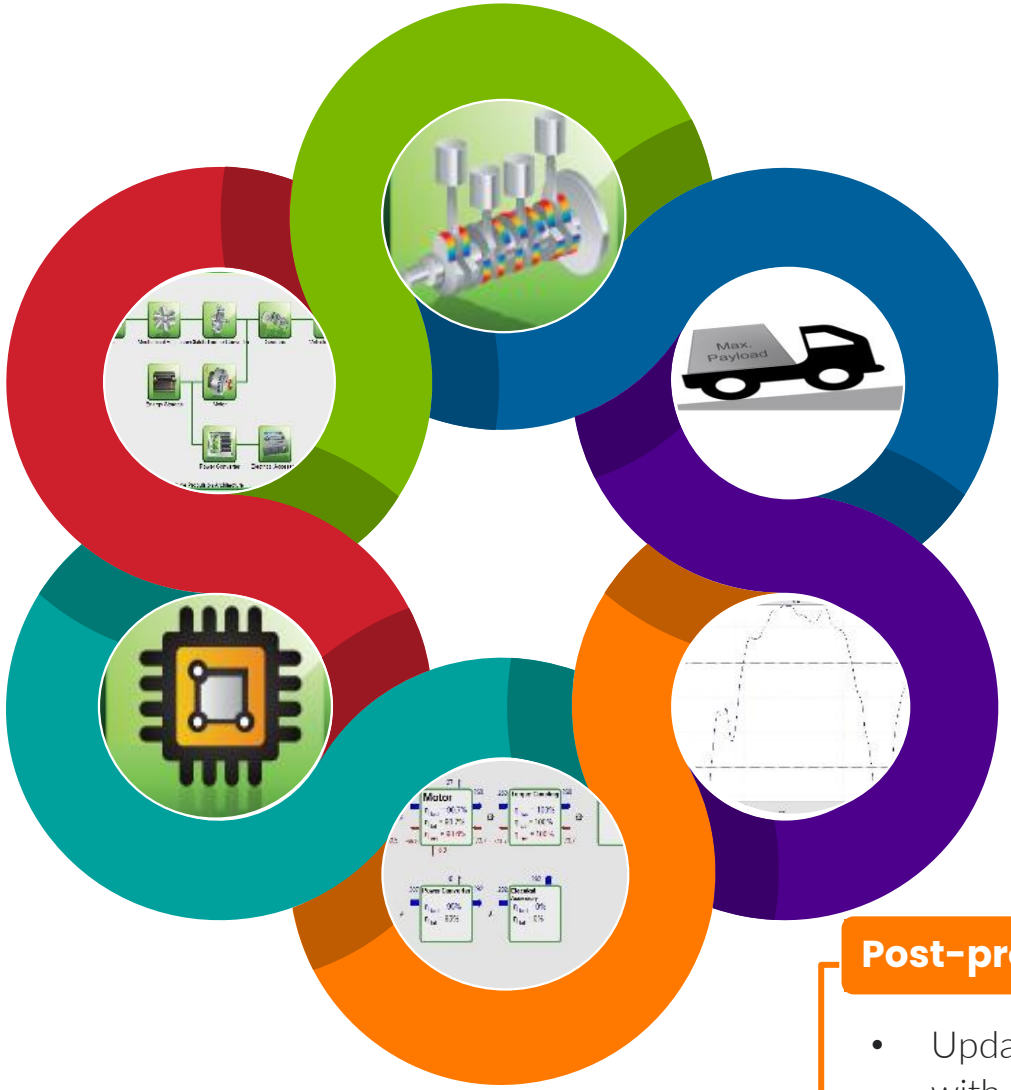
57 New HD & MD Vehicles of various vocations

Powertrain Configuration

- Multimotor BEV architecture

Models and Control

- Fuel Cell Hybrid control for battery dominant architectures
- Multimotor BEV architecture
- Concatenate drive cycles
- Charging along a route



Powertrain Sizing

- New Architectures and improved component capabilities impacts sizing

Driving Cycles

- New China light-duty vehicle test cycle (CLTC)

Post-processing

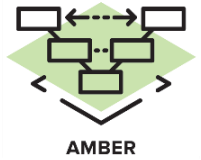
- Updated GHG calculations with latest GREET results

AUTONOMIE LITE – BRINGING AUTONOMIE FIDELITY TO ALL STAKEHOLDERS

Increase Tool Adoption by Targeting Vehicle Model Users (vs Developers)

Vehicle system model developers

New flexible compilation workflow (all parameters accessible)



Vehicle system model users

Deployed to AECOM & CTE which are consultants for municipal transit agencies

Request Autonomie or Autonomie LITE under:
https://license-request-vms.es.anl.gov/nongovernment/amber?release=latest&packageClass=Autonomie

Benefits

FREE

- 100+ ready to go vehicles across vehicle classes, powertrains…
- No fidelity loss
- No Simulink, Stateflow licenses
- Full flexibility in changing component maps, parameters, control calibration
- Runs all standard Autonomie Workflows and procedures
- Run 5x faster than the Simulink Autonomie model

Applications

- Powertrain sizing
- Control calibration
- Component technology impact
- Sensitivity Analysis
- Evaluating cycles and test procedures.

AUTONOMIE EXPRESS – ASSESSING ENERGY IMPACT AT SCALE (MICRO, MESO…)

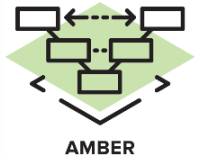
Enables accurate and computationally efficient energy assessment at scale

VTO Benefit Analysis (VAN023)

Vehicle system model developers

Non-Vehicle experts

New flexible compilation workflow (few selected parameters accessible)



A Linux version is under development to support SMART Workflow HPC deployment

Supports: EEMS093, EEMS109, EEMS083 VAN023, VAN035 ,VAN038; NHTSA

Request Autonomie EXPRESS:
https://license-request-vms.es.anl.gov/nongovernment/amber?release=latest&packageClass=Autonomie

Benefits

FREE

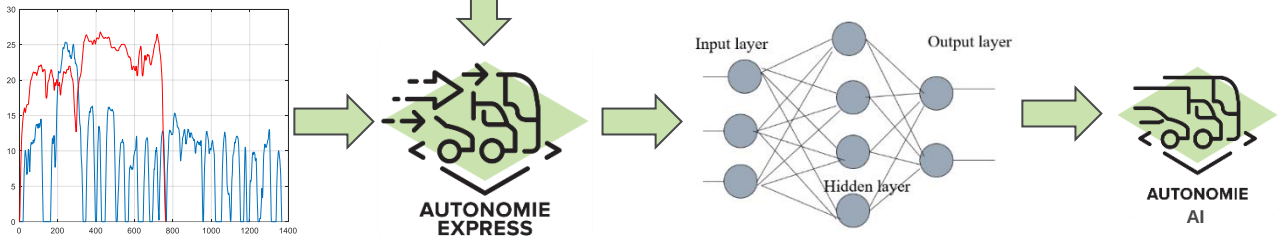
- Free no license fee
- 5,000+ ready to go vehicles across timeframes, vehicle classes, powertrains, technologies…
- No fidelity loss
- No Simulink, Stateflow licenses
- Consistent scenarios across tools
- Runs 100x faster than Simulink Autonomie model

Applications

- CAVs control (e.g., RoadRunner)
- Microsimulation tools (e.g., SUMO, AimSun, VISSIM)
- Mesoscopic tools (e.g., POLARIS)

AUTONOMIE AI – FOCUS ON EXTREMELY EFFICIENT COMPUTATION

Supports Co-Simulation with other Tools as well as Complex Optimization



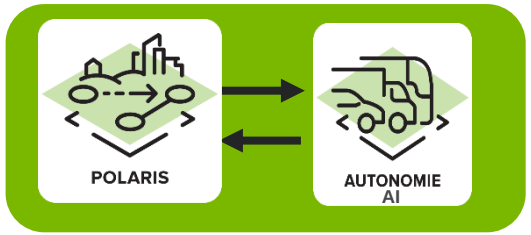
Compiled vehicles from SMART mobility projects are used to generate training set

EEMS093

25 real-world drive cycles and 25 standard cycles

We developed a streamlined process for training data generation
- Using our HPC capabilities
- Generated individual data sets for each vehicle and cycle

Enables cosimulation and embedding of the model



EEMS093

- Eco-routing
- Charging station placement

Release coming soon…

Benefits

FREE

- No 3rd party license
- Minimize Autonomie simulations for known powertrains and technologies
- 10,000 faster than an Autonomie Simulink model up to 100,000 faster with GPU acceleration

Applications

- Battery electric vehicle state-of-charge estimation for charging decision (e.g., co-simulation with POLARIS)
- Fast/efficient powertrain-route recommendation
- Eco-routing
- BEV

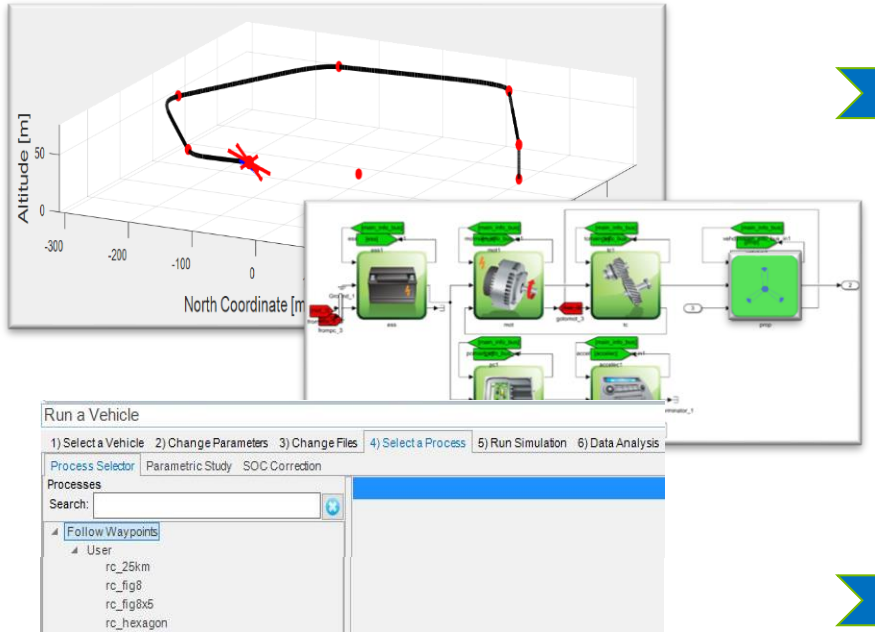
AERONOMIE: “AUTONOMIE FOR AIRCRAFT”

Developing Models of Aircraft for Urban Air Mobility (UAM)

A new mode of transport

- Electric-Vertical Take-Off and Landing (eVTOL)
- A broad range of possible designs (e.g. w/ or w/o wings), passenger capacity, range, etc.

A new tool for low-carbon aviation



- Reuses AMBER core, GUI
- Aircraft-specific models and features
- Featuring drone models (e.g. quadcopters) and fixed-wing aircraft

New eVTOL Models for UAM

- Model will include:
  - Aerodynamics of the airframe
  - multiple motor-propeller blocks and battery
  - Flight control, incl. transitions between different flight modes (hover, climb, cruise).
- Will enable research on:
  - **energy consumption**
  - **component requirements**
  - **optimization** for energy-efficiency

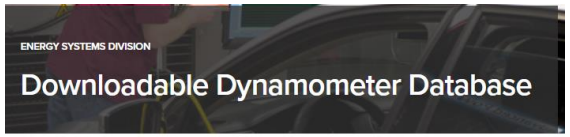
Beta Release end of CY2022

DOWNLOADABLE DYNAMOMETER DATABASE

Extensive data sets provided to understand control and build vehicle models

www.anl.gov/d3

+ linkage to Livewire



Publicly available testing data for advanced technology vehicles

The Downloadable Dynamometer Database (D^3) offers publicly available testing data regarding advanced technology vehicles. Derived from independent laboratory testing, the data is intended to enhance the understanding of advanced vehicle technologies for researchers, students, and professionals engaged in energy efficient vehicle research, development and education.

Data from this website can only be used with the following attribution: "This data is from the Downloadable Dynamometer Database and was generated at the Advanced Mobility Technology Laboratory (AMTL) at Argonne National Laboratory under the funding and guidance of the U.S. Department of Energy (DOE)" or using a standard bibliographic reference.

How to Use the D^3

Select one of the vehicle types below, and on the resulting page, click on a vehicle image. You will be taken to a page from which data on the selected vehicle may be downloaded.

Data is available for the following vehicles:

- 2017 Ford F150
- 2016 Mazda CX9
- 2014 Chevrolet Cruze Diesel
- 2014 Mazda 3 iEloop
- 2013 Dodge Ram 1500 HFE
- 2013 Hyundai Sonata
- 2013 Nissan Altima
- 2013 Volkswagen Jetta TDI
- 2012 Chrysler 300
- 2012 Fiat 500 Sport
- 2012 Ford F150 Ecoboost
- 2012 Ford Focus
- 2012 Ford Fusion V6
- 2010 Mazda 3 i-stop
- 2010 SmartCar MHD
- 2010 VW Golf TDI Bluemotion
- 2009 Volkswagen Jetta TDI

Data is available for the following vehicles:

- 2015 Honda Accord Hybrid
- 2013 Chevrolet Malibu Eco
- 2013 Ford Cmax Hybrid
- 2013 Honda Civic Hybrid
- 2013 Volkswagen Jetta Hybrid
- 2011 Hyundai Sonata
- 2010 Ford Fusion Hybrid
- 2010 Honda CR-Z
- 2010 Honda Insight
- 2010 Toyota Prius
- 2010 Mercedes S400h BlueHybrid

Data is available for the following vehicles:

- 2015 Chevrolet Spark EV
- 2015 Kia Soul Electric
- 2015 Mercedes-Benz B-Class Electric Drive
- 2015 Volkswagen e-Golf
- 2014 BMW i3BEV
- 2014 Smart Electric Drive
- 2013 Ford Focus Electric
- 2013 Nissan Leaf SV
- 2012 Mitsubishi I-MiEV
- 2012 Nissan Leaf

Objectives

- Refine data management processes for DOE VTO internal and public posting of on-dyno and on-road datasets
- Management of data distribution of detailed vehicle testing data with stakeholders (Livewire / D3 as applicable)

Benefits

- Faster and more detailed access to more comprehensive data sets for EEMS stakeholders

Applications

- Revised vehicle and test summary and data distribution process for use in current and future testing activities
- Standardized datasets with metadata and updated summaries for the next generation of dyno & on-road datasets
- Updating of D3 dataset sharing processes (PII processing, data connections with Livewire)

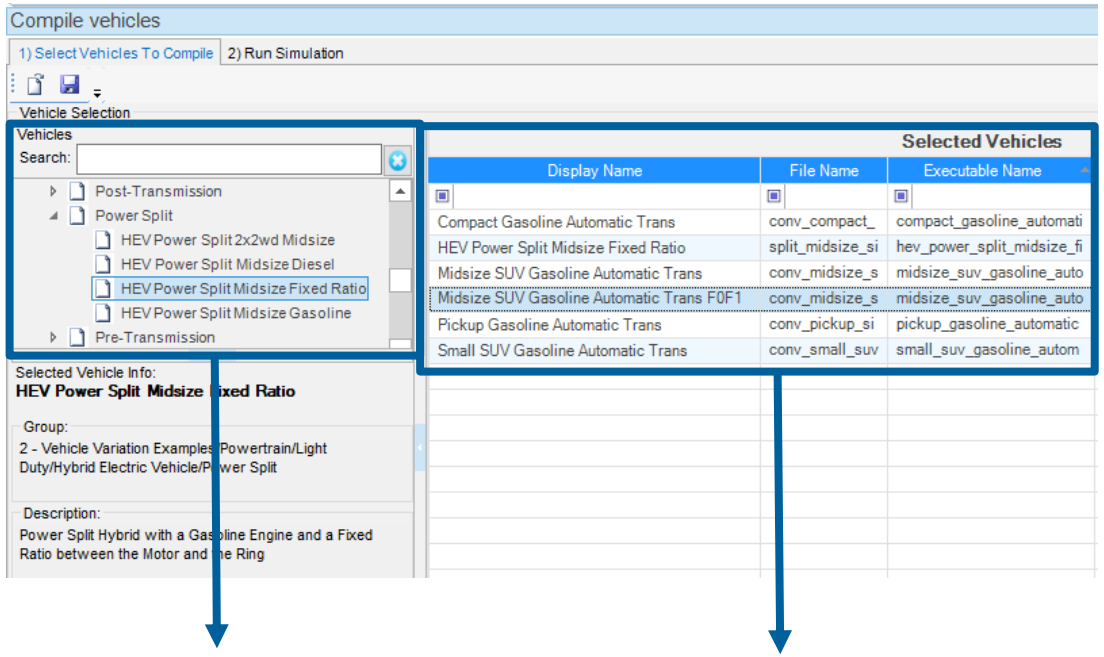
STAKEHOLDER INPUTS DROVE CAPABILITIES AND IMPROVEMENTS

AMBER

AMBER/Autonomie 2022 Release

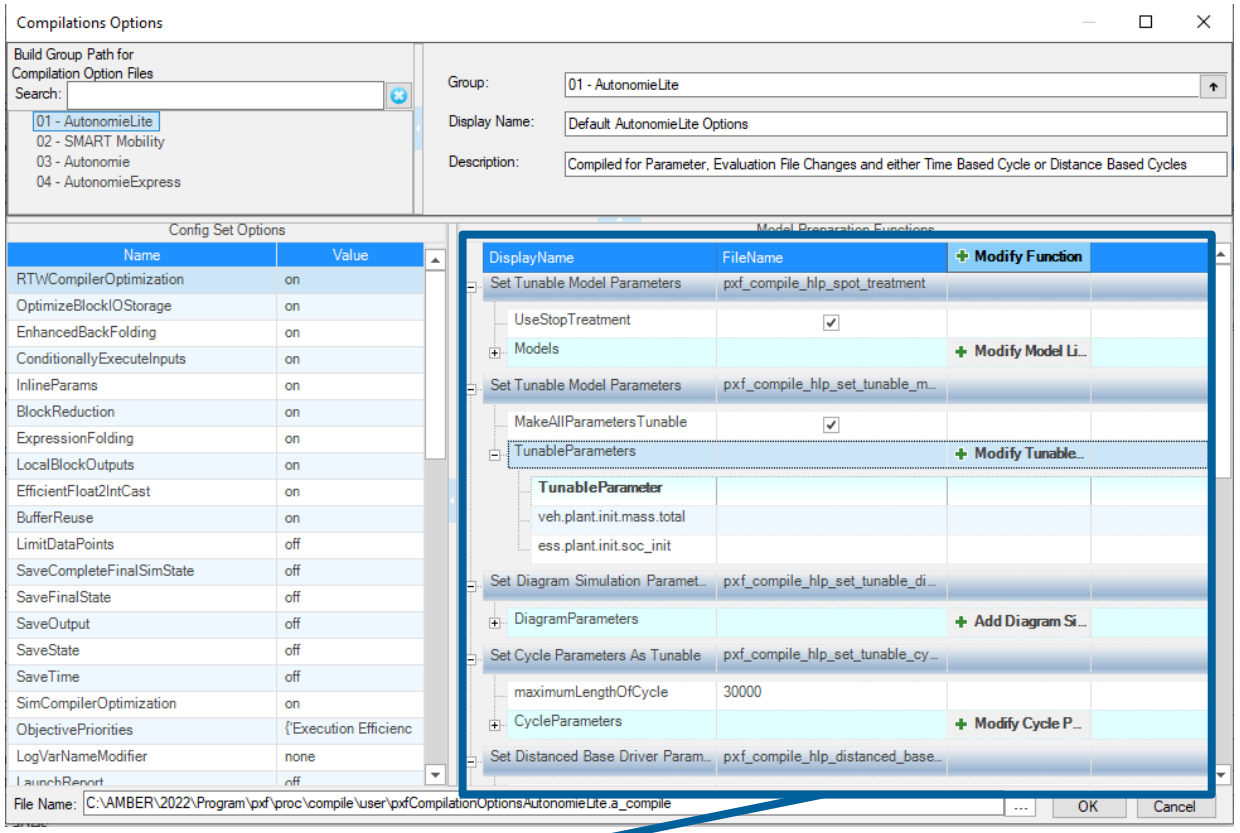
- Supports
  - EEMS109 Cummins
  - EEMS093 SMART workflow on Linux cluster

120+ New Features and Enhancements Added Based on User Feedback



Search for vehicles to compile

Compile 100s of vehicle at once in parallel



Change compilation options: allocated space for variables, maps, cycles

For AutonomieExpress & AutonomieLite

AUTONOMIE EXPRESS

LITE
AUTONOMIE LITE

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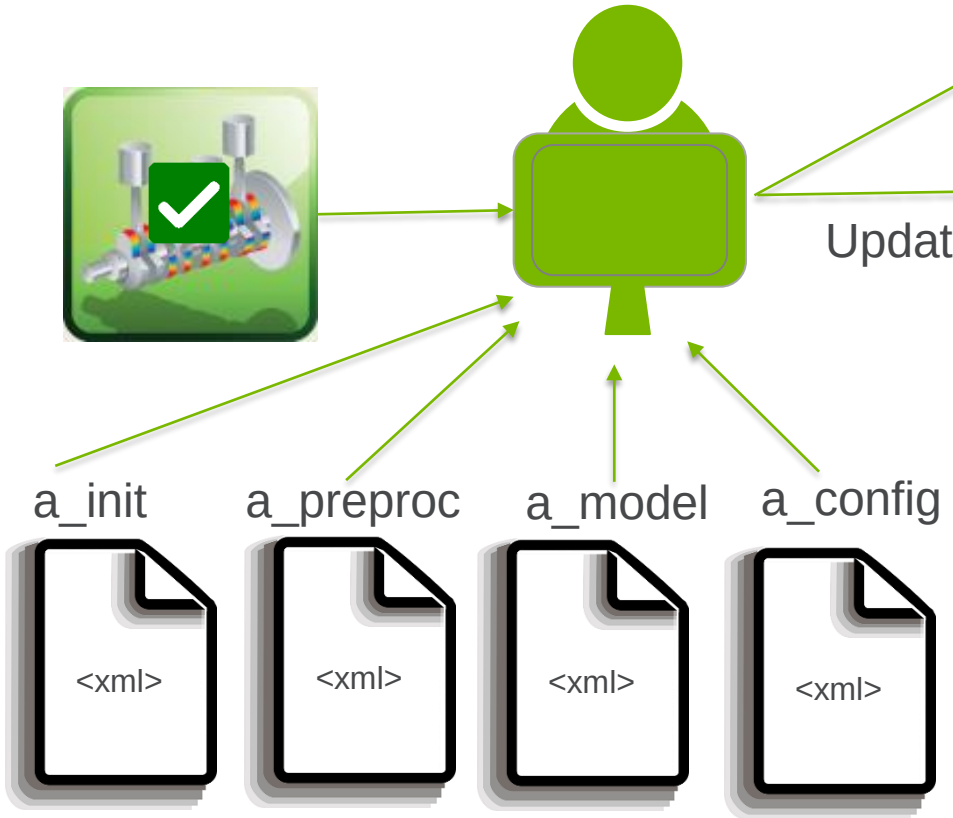
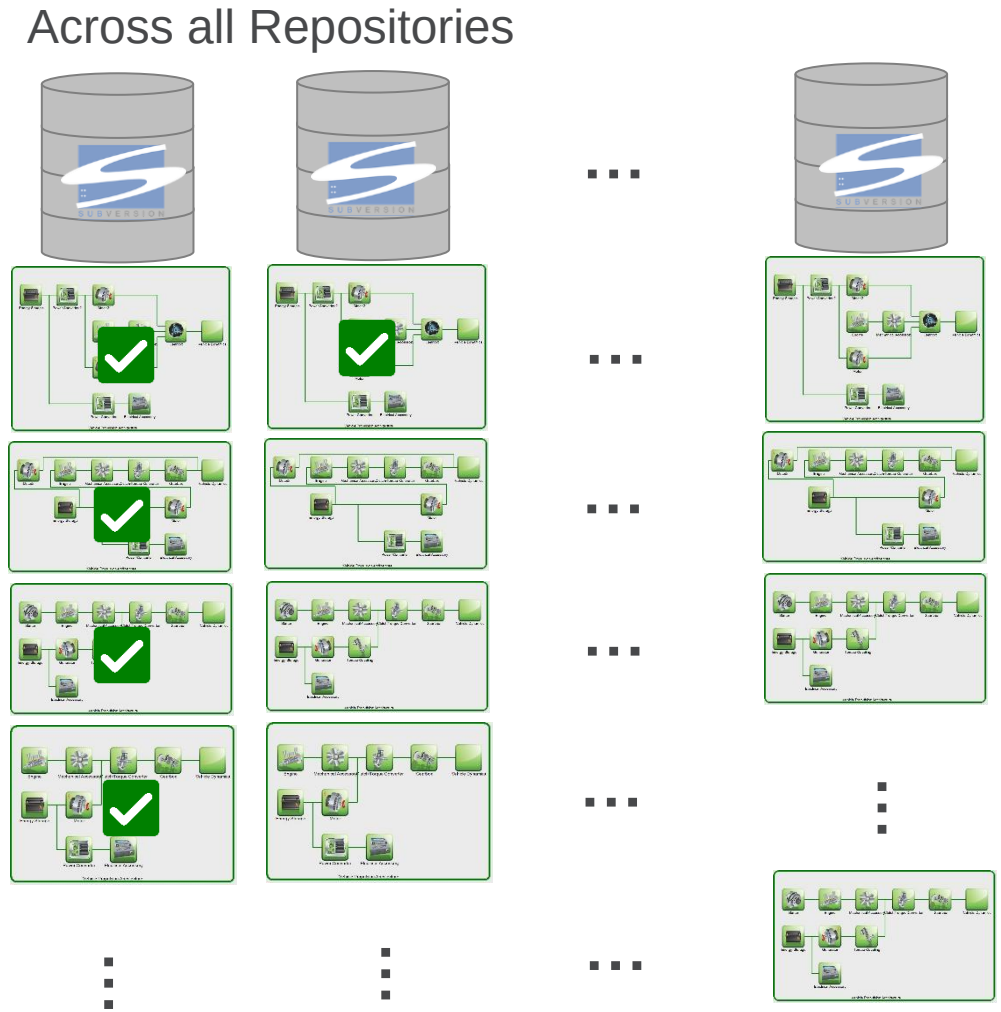
STAKEHOLDERS REQUESTED NEW LIBRARY MANAGEMENT

Having vehicles reference each dependent file instead of copying & pasting reduces the burden on developers

- A single study can generate 1.5 million individual vehicles. To propagate an architectural change to all of those vehicles is burdensome
- Our users have encountered the same issue time and time again.
- Scripting and other less formalized methods have been developed, but they are often one-offs and error prone.





STAKEHOLDERS BENEFIT FROM RUNNING WORKFLOWS ON HPC LINUX

AMBER

Moving the workflow to Linux allows scaling on HPC

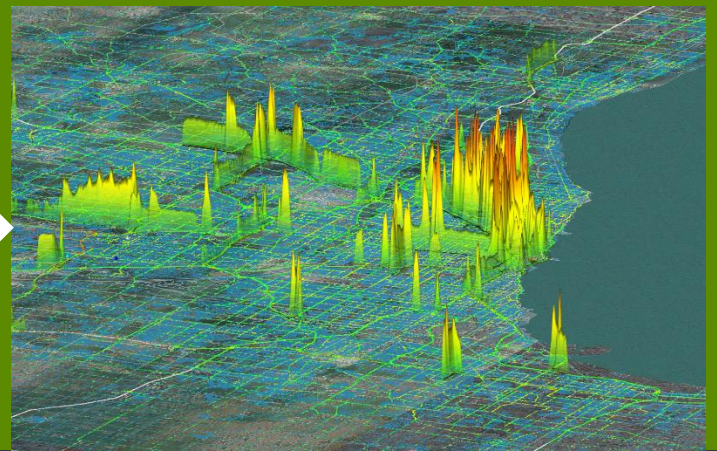
- Migrating the workflow to Linux accelerates research with less effort from researchers for they do not have to coordinate the data sharing between software running on different architectures

- Supports
  - EEMS109 Cummins work
  - EEMS093 Linux cluster

POLARIS

SV TRIP

AUTONOMIE EXPRESS

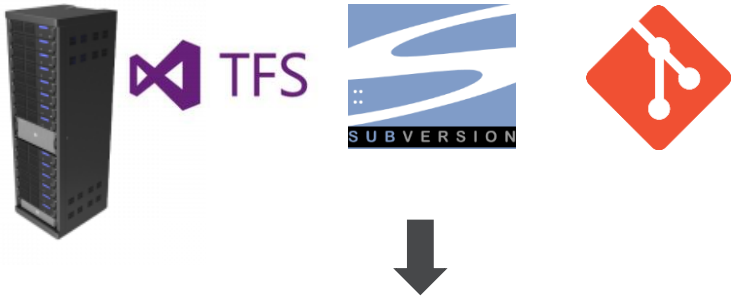


NEW DEPLOYMENT INFRASTRUCTURE AND LICENSE MANAGEMENT

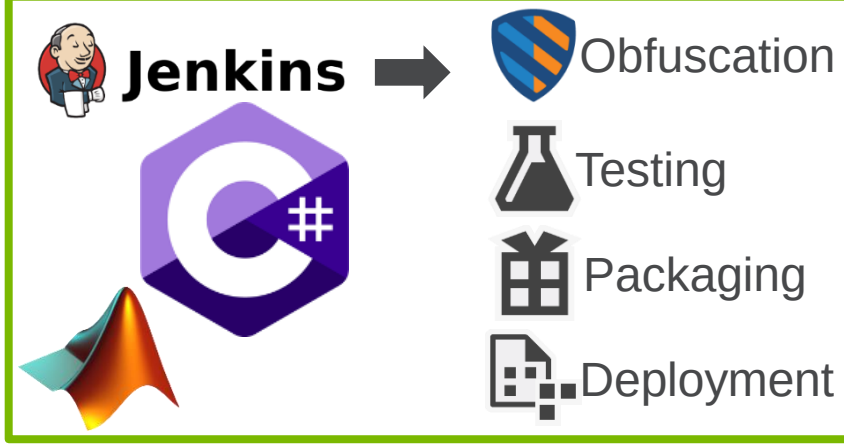
AMBER

Required to Manage Increasing Number of Tools and Workflows

Integrated Source Control



Automated Release Generation



New License Management Features

1) Updated to latest encryption and hashing standards for packaging
2) Added Maintenance tracking in the database
3) Created the ability to edit mac addresses, and other license fields in the database

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RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

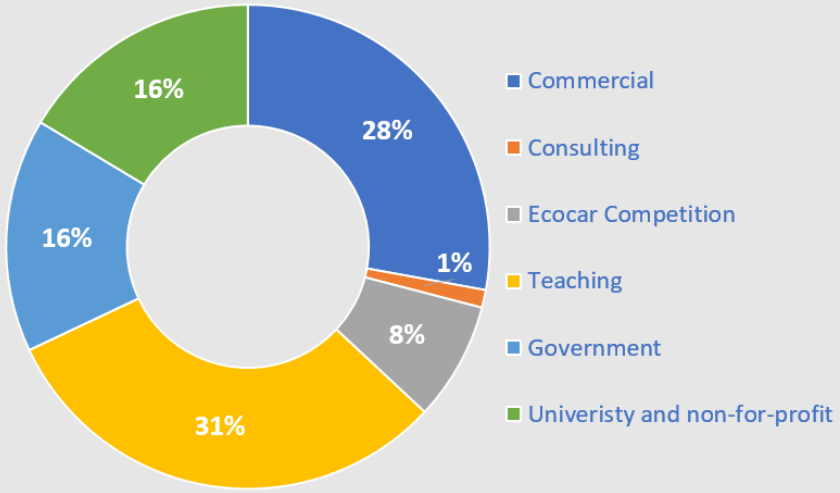
- Question : Approach to performing the work
  - One reviewer expressed concerned over the collection and integration of complex models. "This level of layering and handoff always adds complexity and uncertainty and can reduce transparency and traceability in the model"
- ***Response**:* Managing complexity, and reducing uncertainty is important. Each "layer" has its own validation process. Autonomie vehicle models are validated using data collected at the AMTL. Tools like RoadRunner are validated using results collected via XIL. The software undergoes extensive Nightly testing to confirm vehicle simulation results are repeatable and no inaccuracies were introduced into the models via refactoring.

- Question : Technical Accomplishment and Progress toward project goals
  - Every year, the presenter(s) conveys how much the model has improved and how powerful it is. This implies that, in fact, there were a lot of weaknesses and gaps in prior years.
- ***Response**:* Technology advances. As computing power and software development tools improve, the tools we develop with them can improve too. We started many years ago with 10 vehicles in a study and now we run millions of vehicles in a single study. We like to consider that this comes from innovation and not fixing weaknesses. However, as improvements and new features are deployed issues are introduced which need resolution, which is true for any software development project.

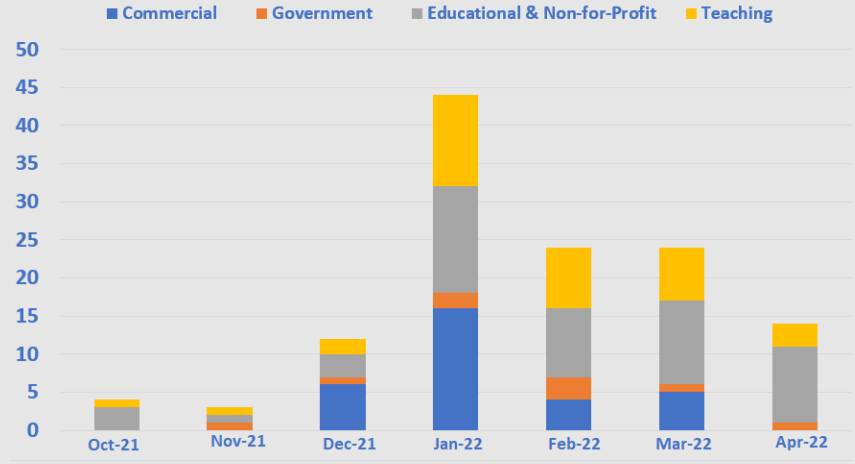
COLLABORATION AND COORDINATION

Core Tools Used Across Companies and R&D Organizations

Over 275+ Licensed Organizations, 650+ users



License Requests (FY22)



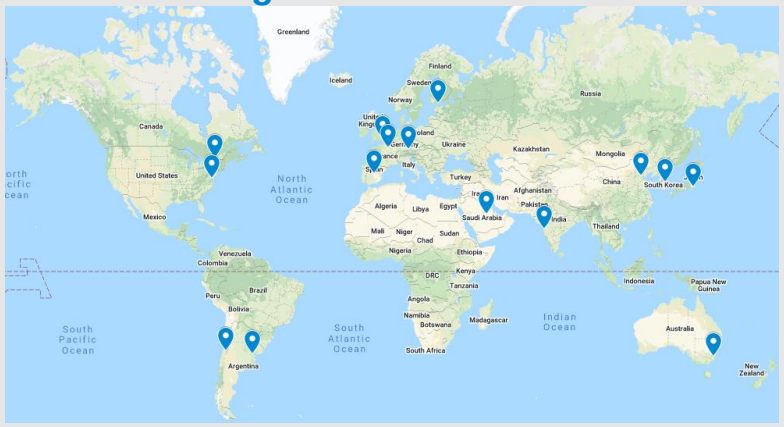
Projects Supported

US DOE (VTO, HFTO), US DOT, US DOD, FOAs, SPPs…

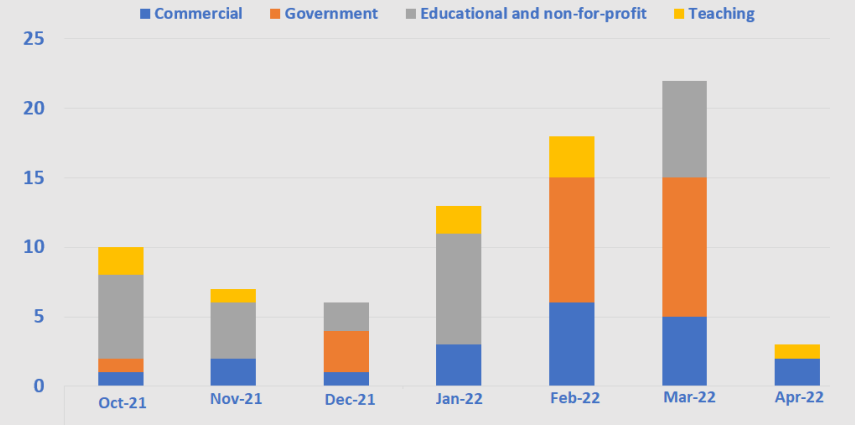
Programs Supported

SuperTruck

Worldwide Usage



Technical Support Requests (FY22)



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COLLABORATION AND COORDINATION

Core Tools Tightly Integrated Across Multiple Projects, Government Agencies

AUTONOMIE	High fidelity vehicle energy consumption, performance and cost	VTO/HFTO Analysis, CIRCLES… EEMS083,EEMS094,EEMS095, EEMS109, VAN017…
LITE AUTONOMIE LITE	Compiled model with full parameter access	AECOM, OEM user base, potential of being used where Autonomie is used now
AUTONOMIE EXPRESS	Compiled model with limited parameter access	SMART Mobility workflow EEMS093
AUTONOMIE AI	Co-Simulation and optimization	POLARIS PEV Charging decision, eco-routing EEMS093
AERONOMIE	Aviation decarbonization	UAM impact on transportation, freight
AMBER	MBSE Worfklows	SMART Mobility workflow, compilation, large scale simulation (HPC) EEMS083, EEMS093
	Deployment	275+ Different organizations run licenses of Autonomie/AMBER, AutonomieExpress
D3	Vehicle testing database	Autonomie models are validated with data from AMTL and used for EEMS083, EEMS093, EEMS109, VAN023,…

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REMAINING CHALLENGES AND BARRIERS OF THIS PROJECT

- Continue to provide professional quality software, including testing, licensing., documentation, training… considering the increased number of tools and workflows
- Manage increasing workflow complexity, involving multiple tools
- Continue to access latest vehicle and component data to represent state-of-the-art technologies
- Access vehicle dynamometer testing to understand latest powertrain and component controls to validate our models, especially for medium and heavy-duty
- Replicate our success for additional transportation modes each with their own challenges (air, rail, boat, microsim etc.)
- Develop component models, vehicles and control, etc.
- Handle and analyze increasing larger data sets generated from data collection, laboratory testing and large scale studies

PROPOSED NEXT STEPS*

Expand Workflow and Model Capabilities

Autonomie Models

- Continue to enhance models, data… to represent state-of-the-art
- Expand new transportation modes (off-road, rail, boats, micro-transit…)
- Add new real world cycles (& deploy)
- Validate vehicle models
- Predictive vehicle design (learn from current vehicle designs)
- Ability to introduce charging events in a daily route

Autonomie Workflows

- Build & deploy workflow to estimate individual component technology benefit including automated control calibration
- Workflows for users (e.g., compiled vehicles, AI, online tool, MathWorks free)
- Predictive vehicle design (ML)
- Powertrain selection for specific routes with grade, cargo
- Expand automated model development & validation
- Build daily route from individual trips

(*) Any proposed future work is subject to change based on funding levels

PROPOSED NEXT STEPS*

Expand Stakeholder Engagement & Deployment

Maintain Tools / Support Users

- AMBER, Autonomie (full, compiled, AI)
- Add SVTrip, RoadRunner, POLARIS, Aeronomie
- Track/address issues and new requirements
- Update 25+ software versions

Expand AMBER

- Expand APIs to support integration of additional 3rd party tools (e.g., xIL)
- New data analytics workflows (including larger datasets, videos…)
- HPC workflow

Deploy Models / Tools / Workflow

- Expand testing across all tools
- Expand training (specific version w/ videos, exercises).
- Select / manage deploy vehicles (2.5M+) and drive cycles

(*) Any proposed future work is subject to change based on funding levels

SUMMARY

Stakeholder Engagement & Deployment

Technical support, training, documentation, software management

Model-Based System Engineering

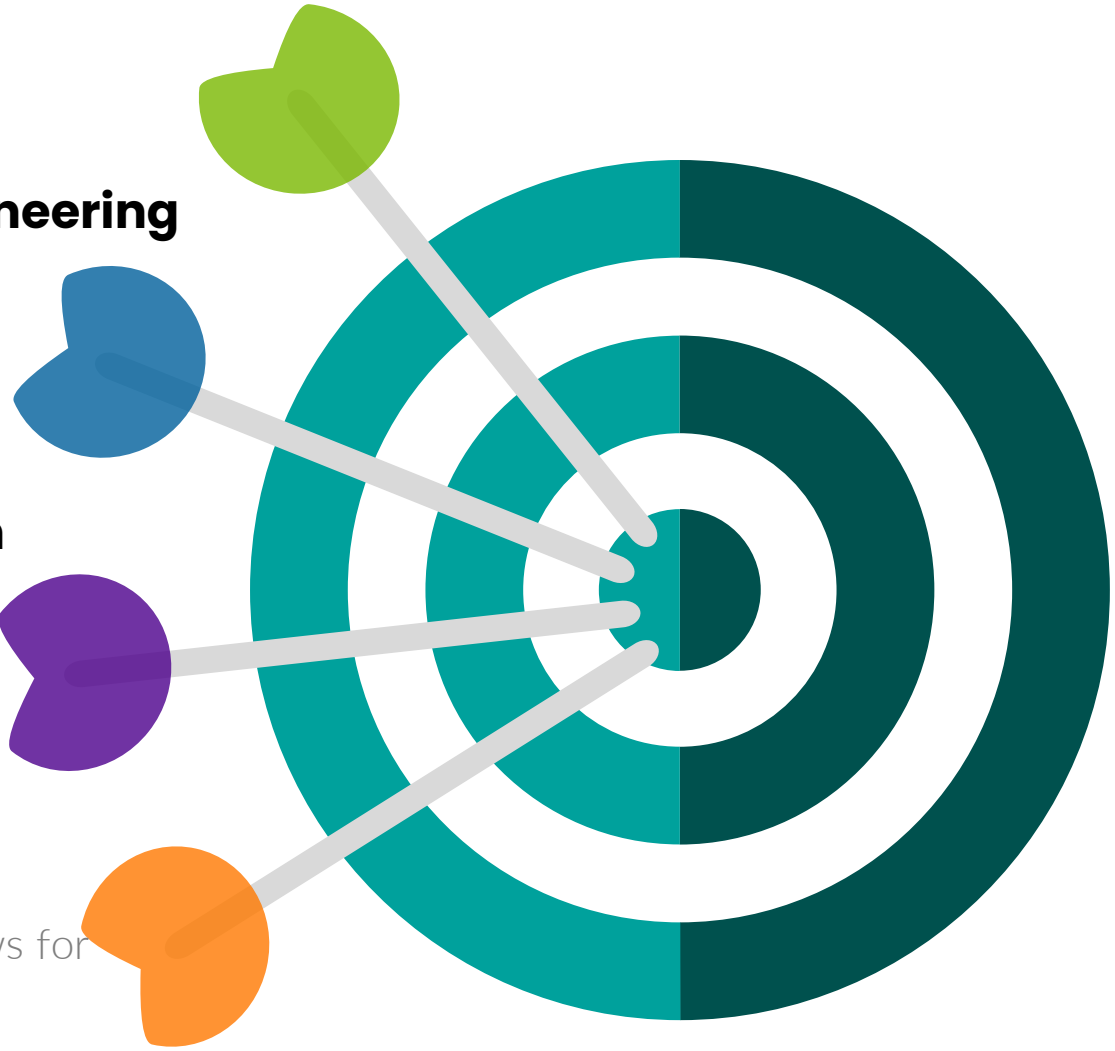
Improved code structure, new license management, enhanced deployment infrastructure

Vehicle System Simulation

New data, models, control, powertrains, improved powertrain

MBSE Workflows

New and improved workflows for vehicle energy consumption, performance and cost (e.g., compiled version, large scale simulation)



Supports

- 30+ VTO & HFTO projects
- 10+ US DOT & DOD projects
- Licensed to 275+ organizations with

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A TANGIBLE BENEFIT TO INDUSTRY

"Autonomie is used extensively at Ford to support model based development, calibration and optimization of Ford's electrified propulsion systems include HEV's, PHEV's, BEV's and FCEV's. The environment provides strong model plug-and play capabilities and a user friendly simulation management structure and interface that enables highly efficient model based system development processes. Use of Autonomie at Ford is a key enabler for reducing reliance on physical vehicle prototypes and accelerating development of new electrified propulsion systems."

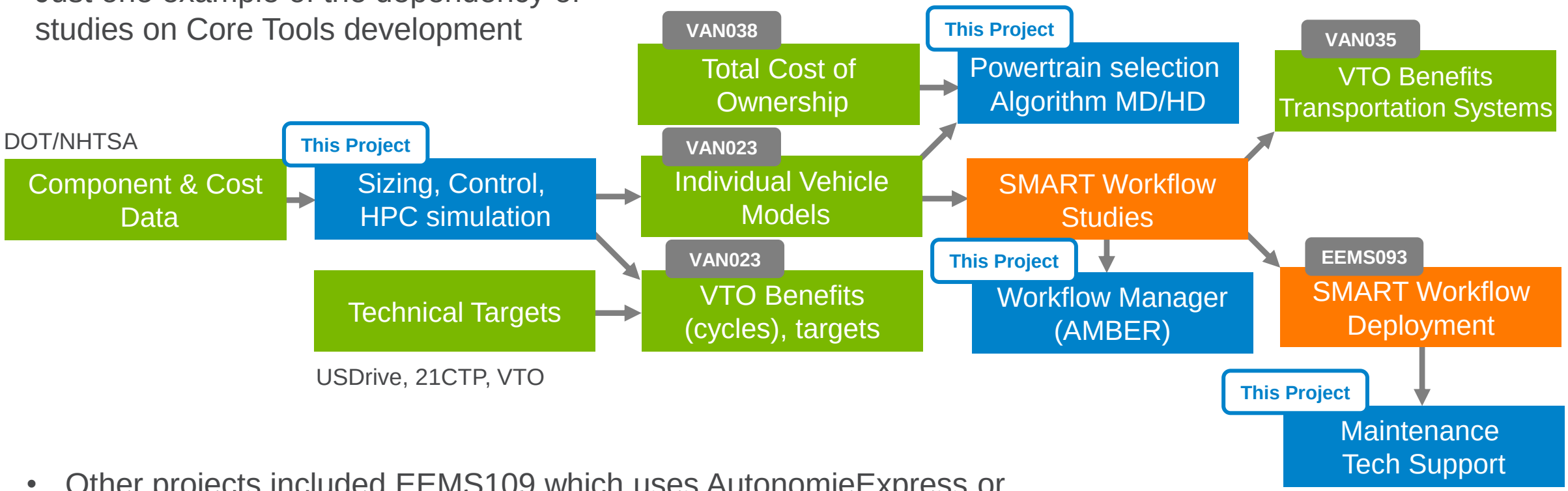
Mark Jennings
Ford Motor Company

QUESTIONS?

COLLABORATION AND COORDINATION

Core Tools Tightly Integrated Across Multiple Projects, Government Agencies

- Just one example of the dependency of studies on Core Tools development

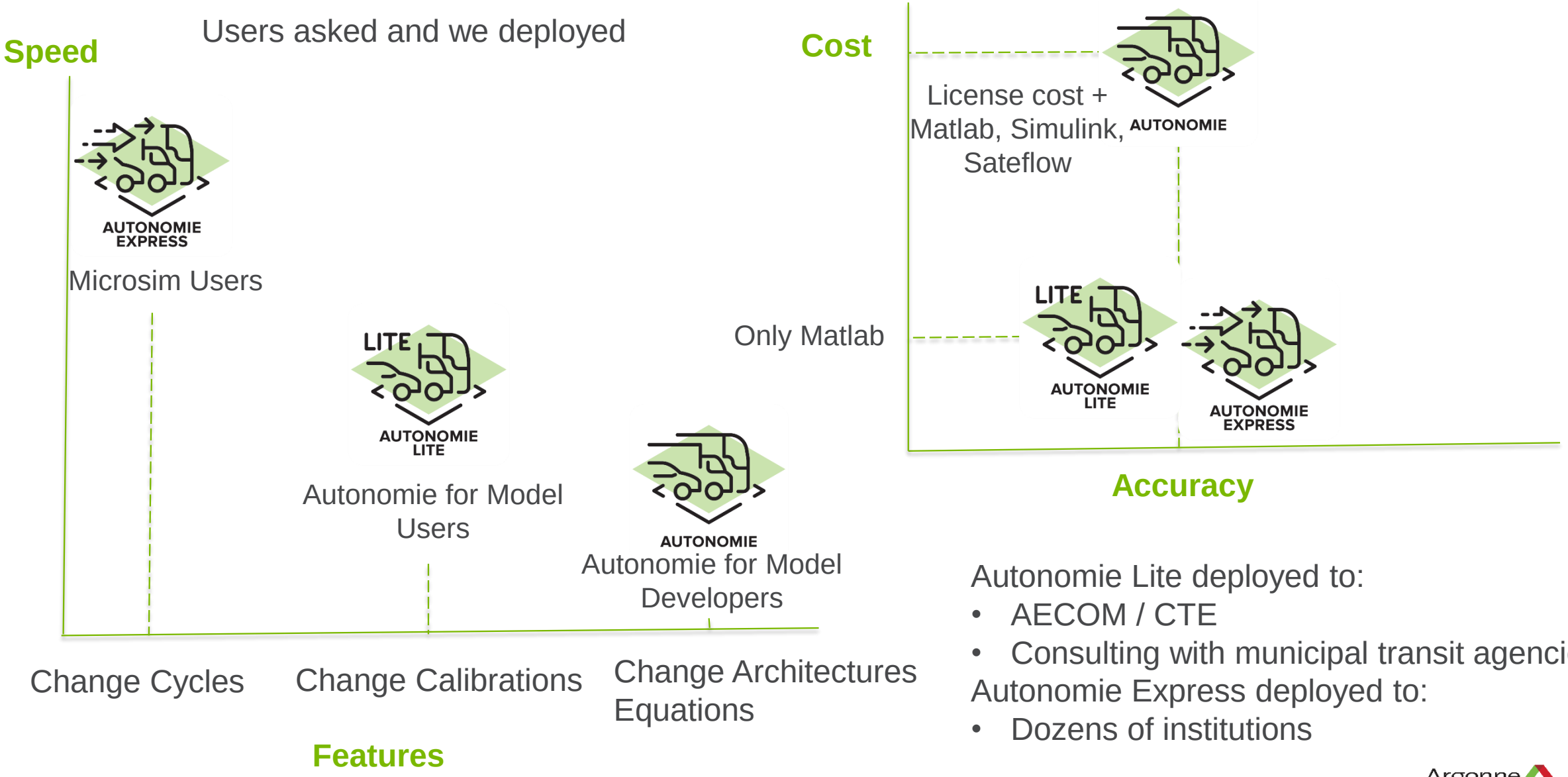


- Other projects included EEMS109 which uses AutonomieExpress or EEMS083 which uses Autonomie
- LPO ATVM program uses Autonomie vehicles and cycles
- NHTSA – benefits from improvements to Autonomie

AUTONOMIE MODELS

- Continue to enhance models, data… to represent state-of-the-art
- Expand to new transportation modes
  - off-road - Engines
  - Rail - HFTO
  - Boats – LPO, ATVM + recreational boating industry
  - micro-transit – SMART mobility
- Add new real world cycles (& deploy)
  - Import cycles from sources like livewire
  - Interface with GTFS General Transit Feed Specification
  - POLARIS => SVTRip =>AutonomieExpress consumptions
  - Better linkage with onboard data collection devices developed by AMTL
- Powertrain thermal modeling
- for EEMS, HFTO, LPO ATVM
- (Class 2b/3 test data from AMTL, component from SWRI) vehicle validation
- FY15 and FY16 HD truck models – feedback from different DOE offices, deploying models that were previous developed to stakeholders, engines and vehicles models used for studies developed as part of earlier DOE research

RESPONDING TO THE REQUESTS OF STAKEHOLDERS WITH RELEASES FOR EACH THEIR USE CASES



Autonomie Lite deployed to:

- AECOM / CTE
- Consulting with municipal transit agencies

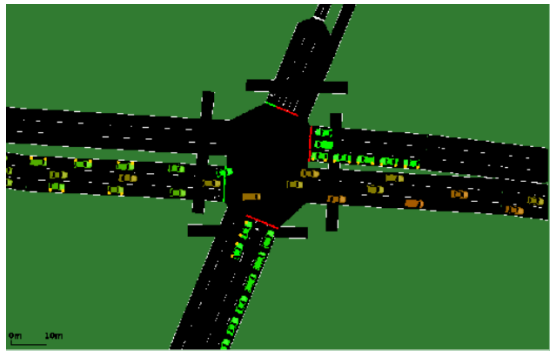
Autonomie Express deployed to:

- Dozens of institutions

NEW WORKFLOW DESIGNED TO ESTIMATE ENERGY, COST FROM MICRO-SIMULATION TOOLS

Most Commonly Used Tools Integrated

Micro-simulation Tools



SUMO

PTV VISSIM

aimsun.

+

AUTONOMIE *EXPRESS*

Five Timeframes (2020, 2025, 2030, 2035, 2040)

✖

20+ vehicle classes from light-duty to medium and heavy duty

✖

Multiple Powertrains (conv, ISG, HEV, PHEV, BEV, FCEV)

✖

Technology Uncertainties

1000s of vehicle models

+

AMBER

Workflow

- Assign Autonomie *EXPRESS* models to individual micro-simulation vehicles
- Simulate using individual vehicle speeds from micro-simulation

=

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